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# Long-term Variation in the Upper Atmosphere as Seen in the Amplitude of the Geomagnetic Solar Quiet Daily Variation

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# IUGONET

Metadata DB for Upper Atmosphere

## The 2nd Nagoya Workshop on the Relationship between Solar Activity and Climate Changes

超高層大気長期変動の全球地上ネットワーク観測・研究

Inter-university Upper atmosphere Global Observation NETwork

2012/1/16-17

# Long-term Variation in the Upper Atmosphere as Seen in the Amplitude of the Geomagnetic Solar Quiet Daily Variation

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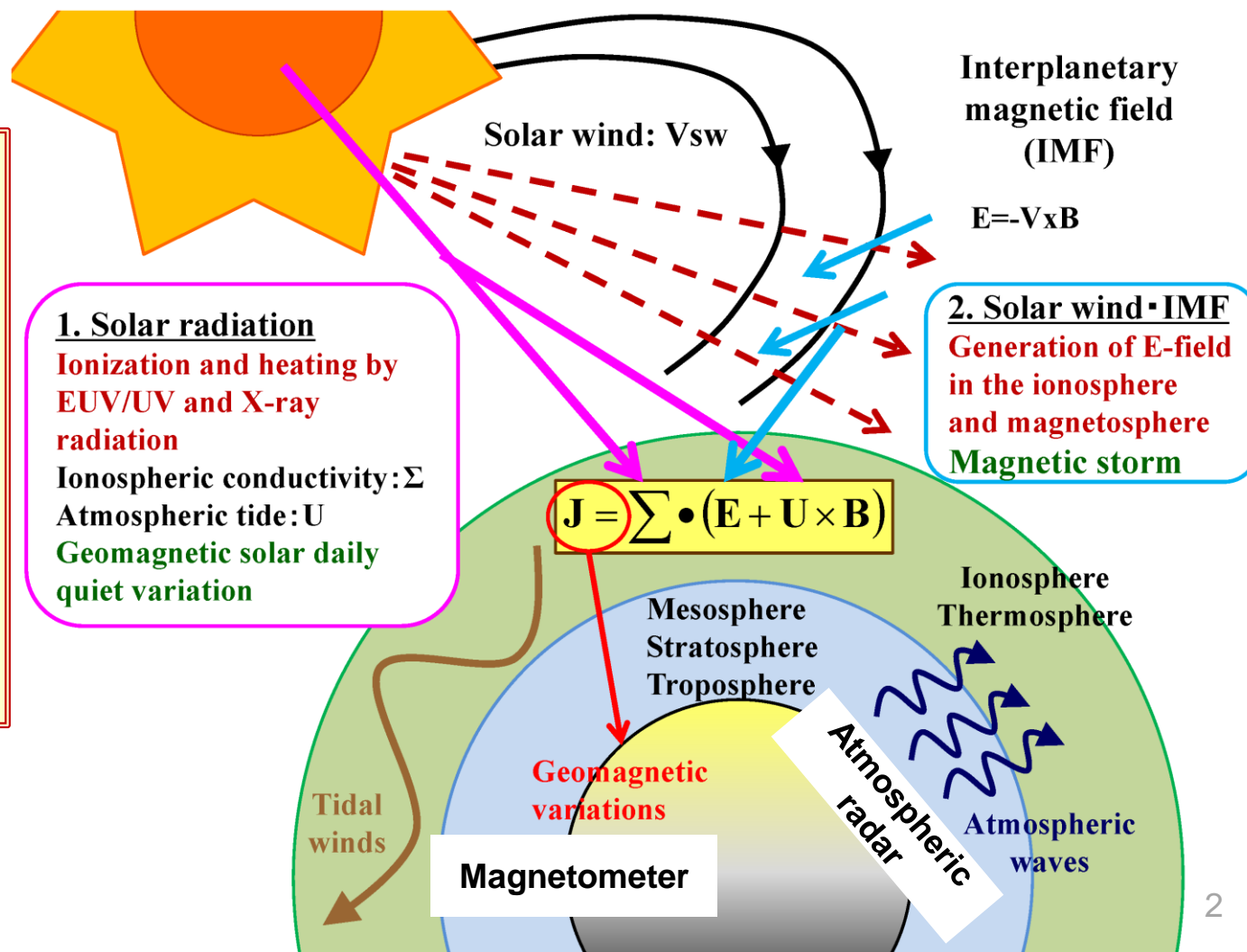
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# 1. Introduction

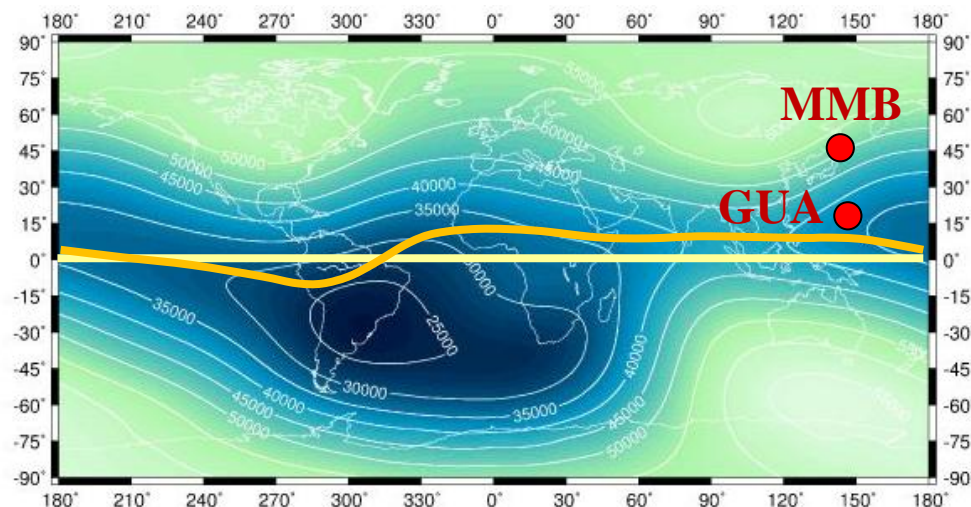
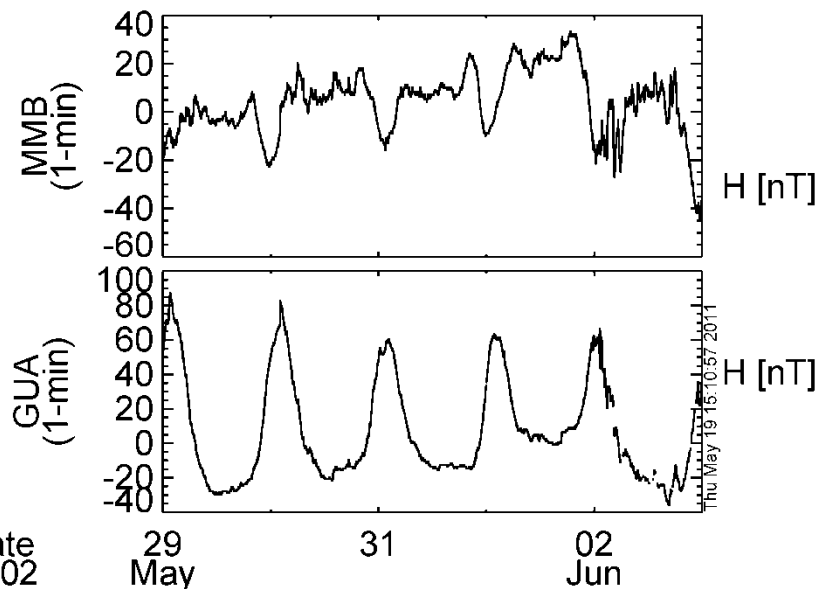
## 1.1 Relationship between solar activity and upper atmospheric variation

To investigate the response of the Earth's atmosphere to solar activity using the long-term observation data is essential for understanding climate change and environment of the planetary atmosphere.



# 1. Introduction

## 1.2 Geomagnetic Solar daily Quiet (Sq) variation



Location of Memanbetsu and Guam

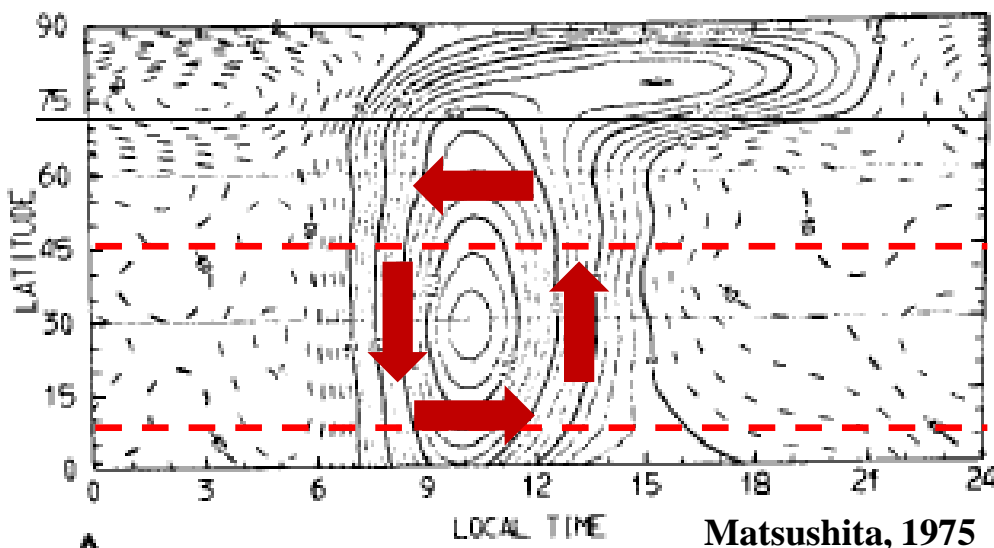
[Origin]

High latitude:

**Ionospheric plasma convection  
driven by solar wind**

Middle and low latitudes:

**Ionospheric dynamo driven by  
neutral wind**





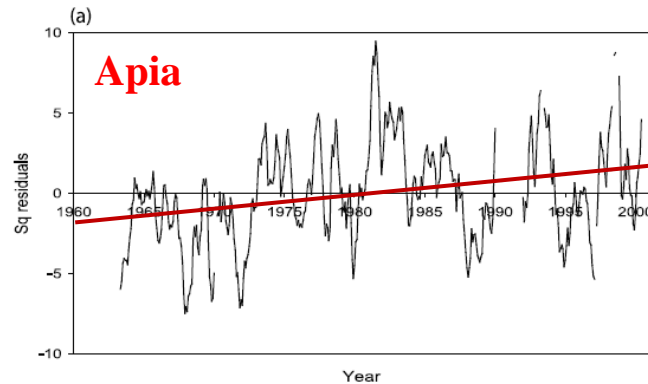
# 1. Introduction

## 1.3 Review of long-term variation in the Sq field

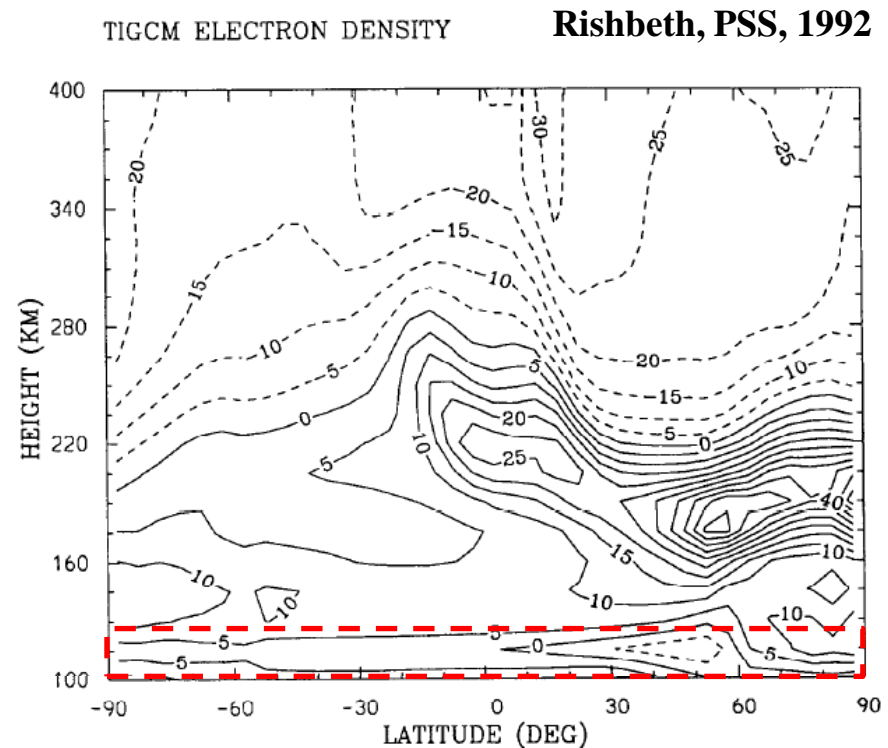
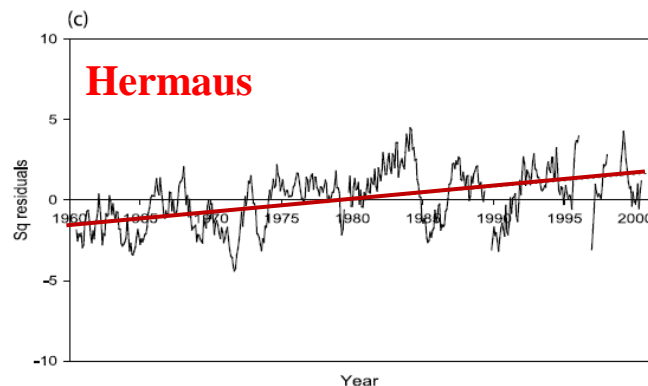
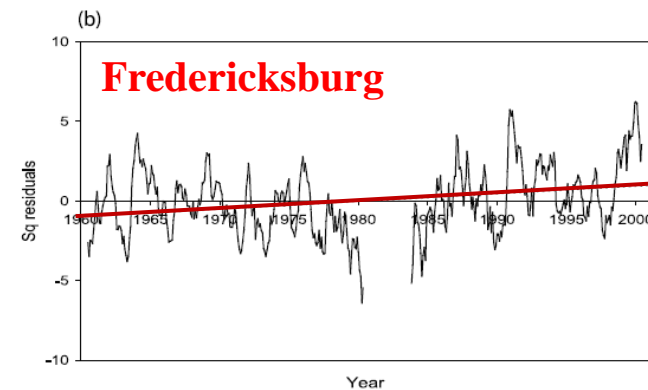
	Obs. points	Solar data	Sq trend	Effect of secular variation of gmag.	Comments
Sellek [1980]	3	Sunspot	Increase	◎	First paper
Schlapp et al. [1990]	11	Sunspot	Increase	◎	Magnitude of Sq trend is different from different observation points.
Macmillan and Droujinina [2007]	14	F10.7	Depend on observation points	◎	Yearly variations of Sq field can be used as a proxy of solar irradiance.
Elias et al. [2010]	3	Sunspot	Increase	◎	Long-term trends in the Sq field is linked to upper atmospheric variation associated with greenhouse effect.

# 1. Introduction

## 1.4 Long-term trends in the Sq field linked to greenhouse effect



Elias et al.,  
JGR, 2010



**Electron density in the ionosphere tends to increase due to the upper atmospheric cooling associated with greenhouse effect. Then, the Sq amplitude tends to increase with increase of ionospheric conductivity.**





# 1. Introduction

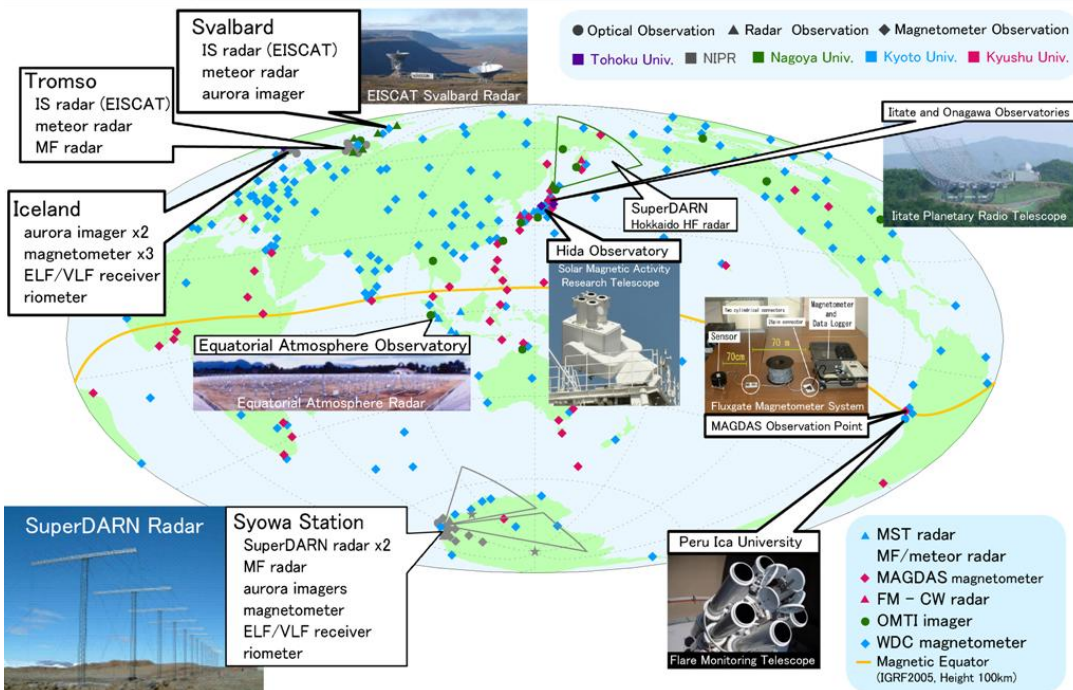
## 1.5 Problems of previous works and purpose of the present study

### [Problems]

#### ○ Shortage of observation points of geomagnetic field and long-term analysis

⇒ Elias et al. [2010] investigate the long-term trends in the Sq fields during 1961-2001 obtained from only 3 observatories. **A global feature of the Sq trends during a very long period remains unknown.**

#### ○ Problems of analysis method and assumption to determine the Sq field.



### [Purpose]

We **clarify the mechanism of the long-term variation in the global Sq field** using the IUGONET observation data.

**Ground-based observation network covering from high latitudes to equator.**



## 2. Observation data and analysis

### 2.1 Observation data

○ Geomagnetic field (1900-2011): WDC, Kyoto U.

Time resolution: 1 hour, Observation points: 200-300

○ Geomagnetic indices (Kp index: 1932-2011) : WDC, Kyoto U.

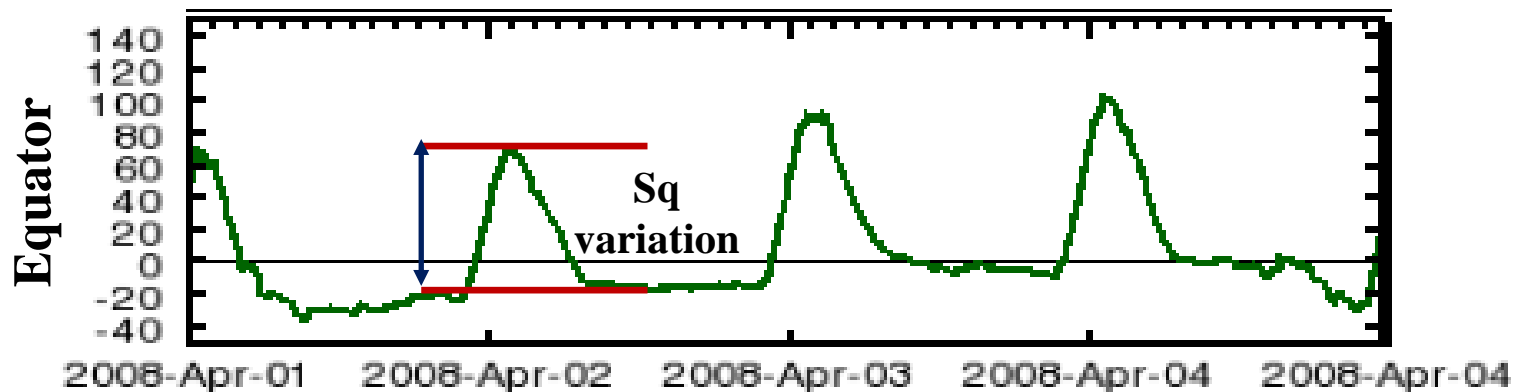
○ F10.7 solar flux (1947-2011) : NGDC/NOAA

### 2.2 Identification of geomagnetic quiet days and Sq amplitude

○ Quiet days: Maximum Kp value is less than 4 for a day

○ Sq amplitude: 1-month average value of difference between the maximum and minimum for each quiet day.

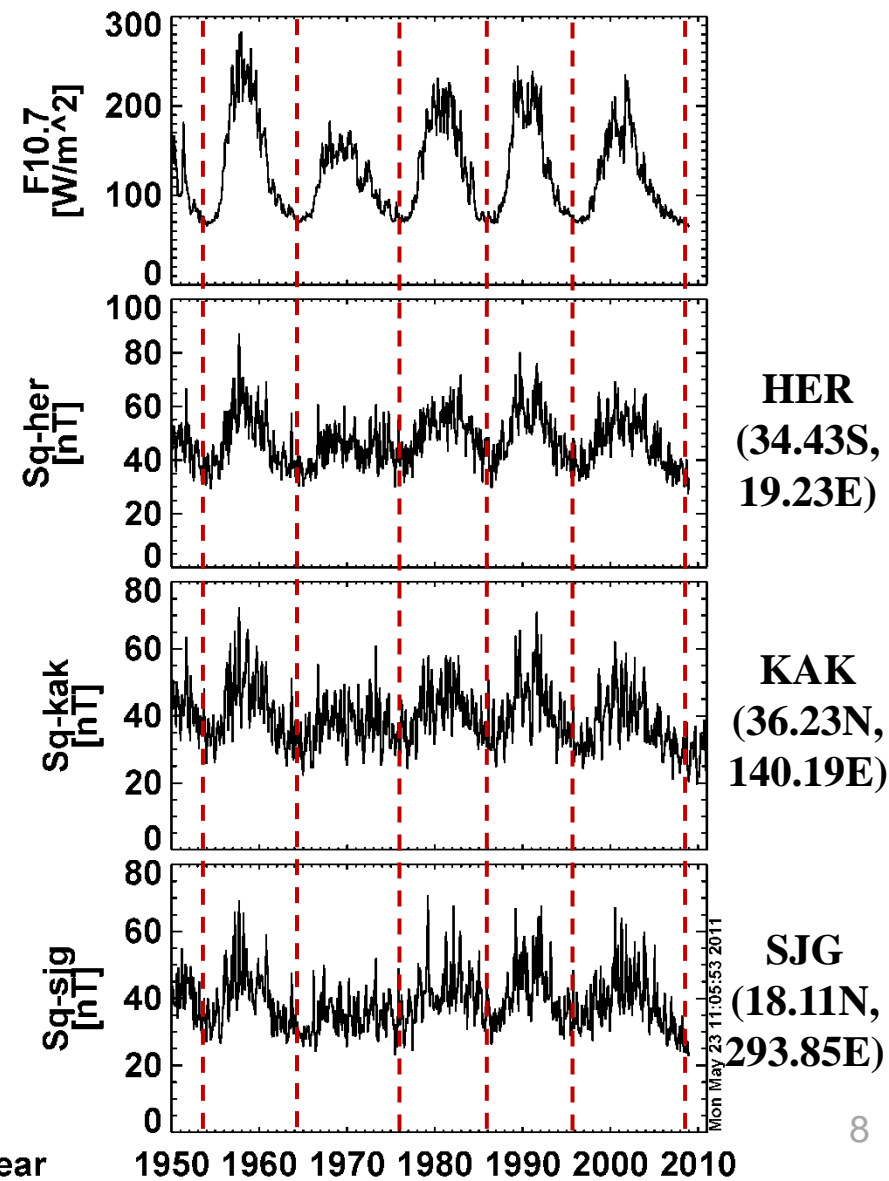
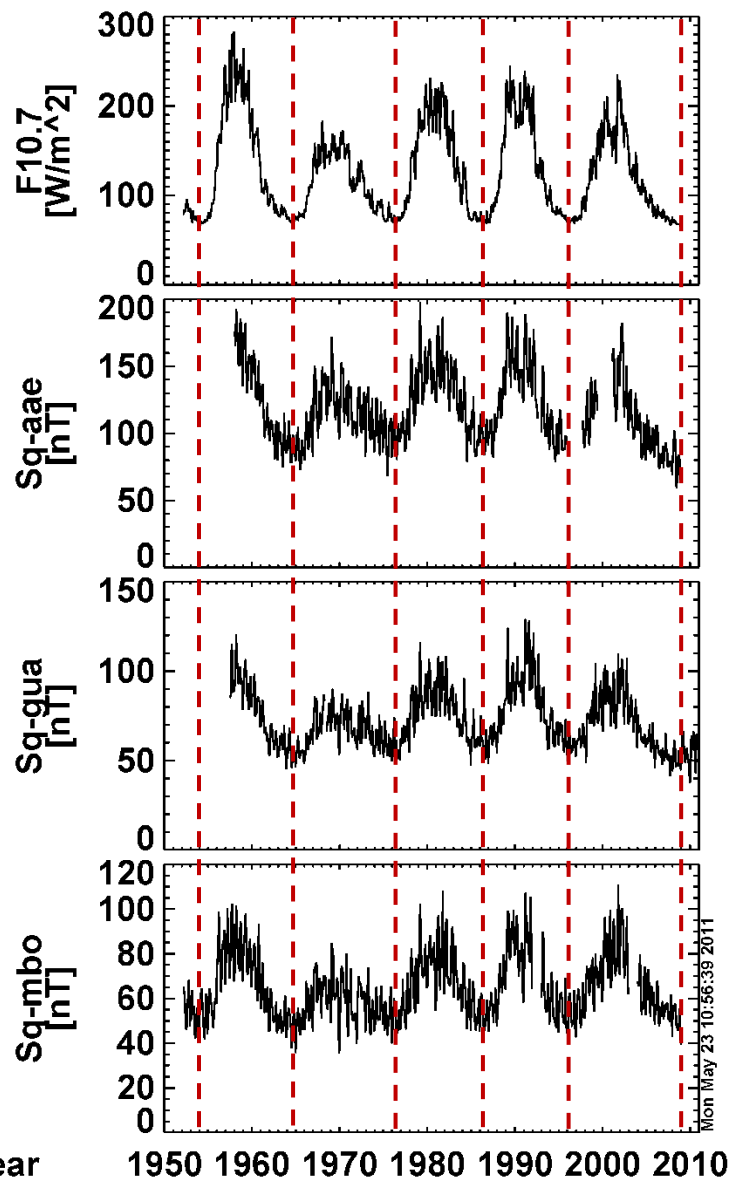
○ Residual solar activity: Deviation from second-order fitting curve.





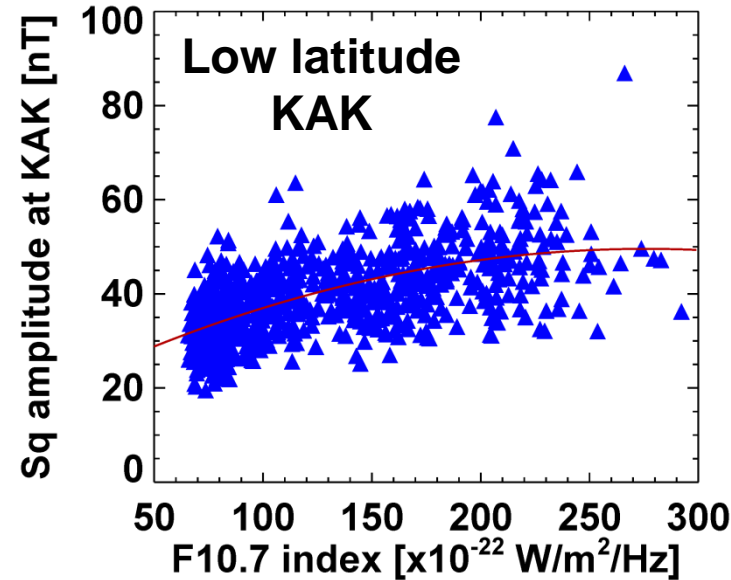
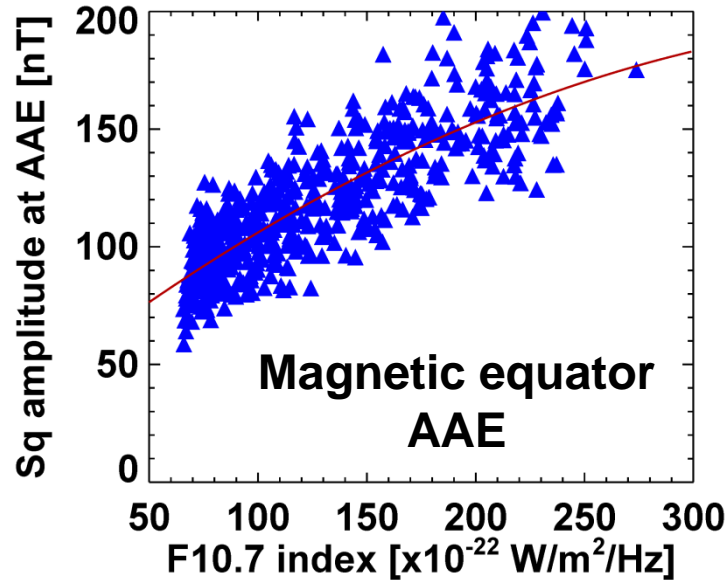
# 3. Results

## 3.1 Long-term variations of the Sq amplitude

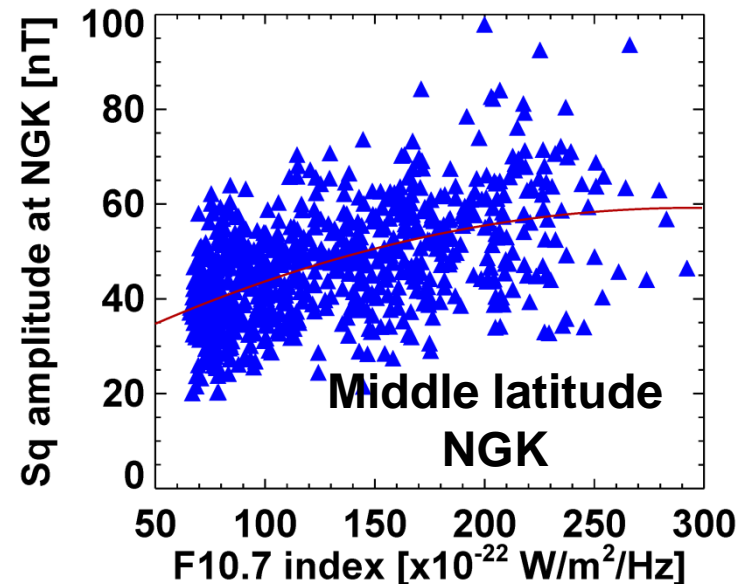
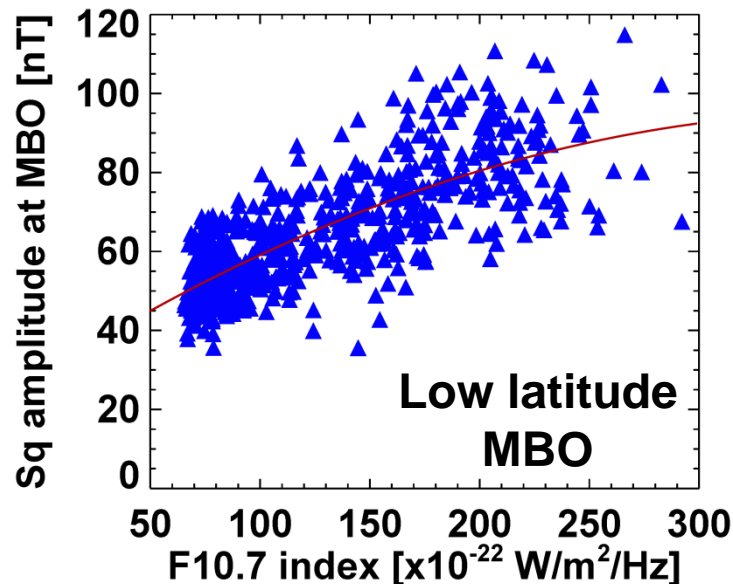


# 3. Results

## 3.2 Relationship between the Sq amplitude and F10.7 index



1-month  
average  
value

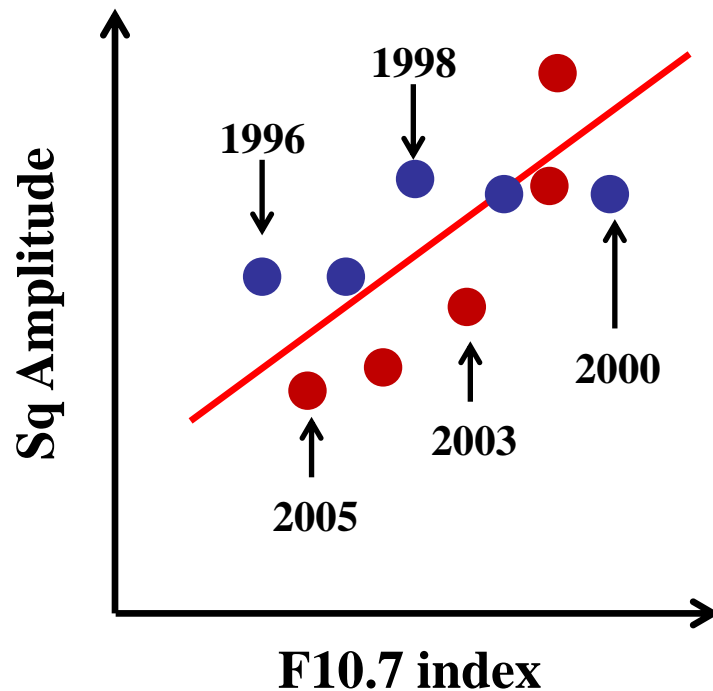


Nonlinear  
relation  
between the  
Sq amplitude  
and F10.7  
index.

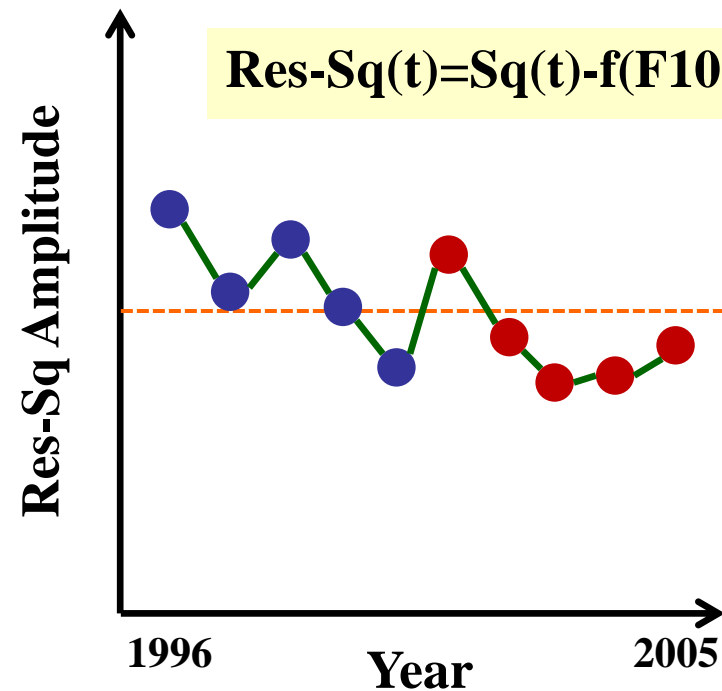
## 3. Results

### 3.3 Deviation of residual Sq amplitude

F10.7 index vs. Sq amplitude



Plot of deviation of the fitted curve.

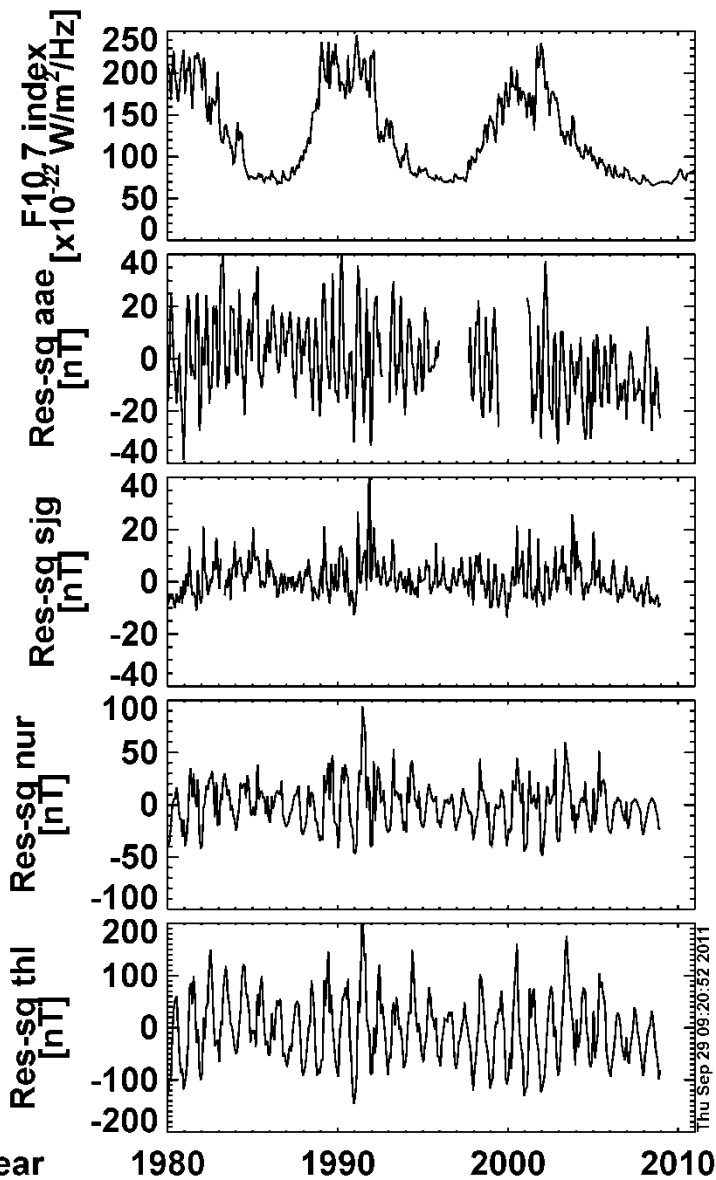


Residual Sq amplitude

= secular variation of gmag. + upper atmospheric variations (neutral density, winds and ionospheric structure)

# 3. Results

## 3.4 Long-term variation of residual Sq amplitude-1



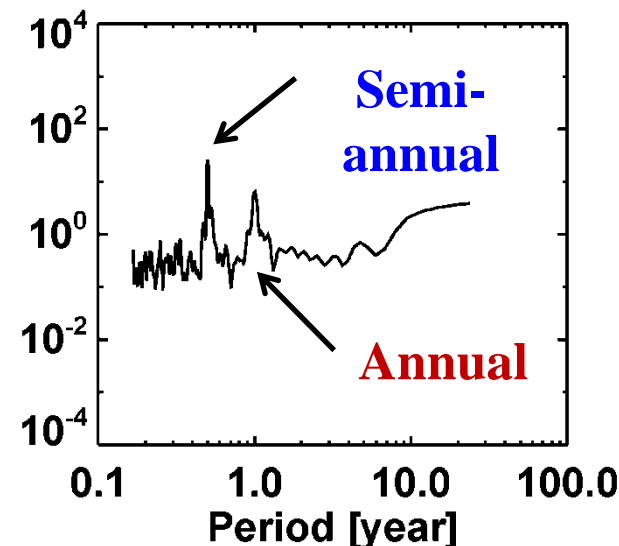
AAE  
(9.03N,  
38.76E)

SJG  
(18.11N,  
293.85E)

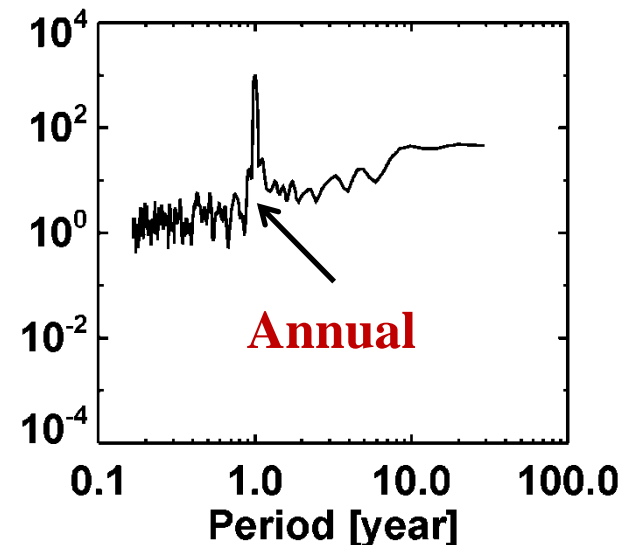
NUR  
(60.50N,  
24.65E)

THL  
(77.48N,  
290.83E)

Res Sq at AAE  
Power spectrum  
[(nT)<sup>2</sup> year]

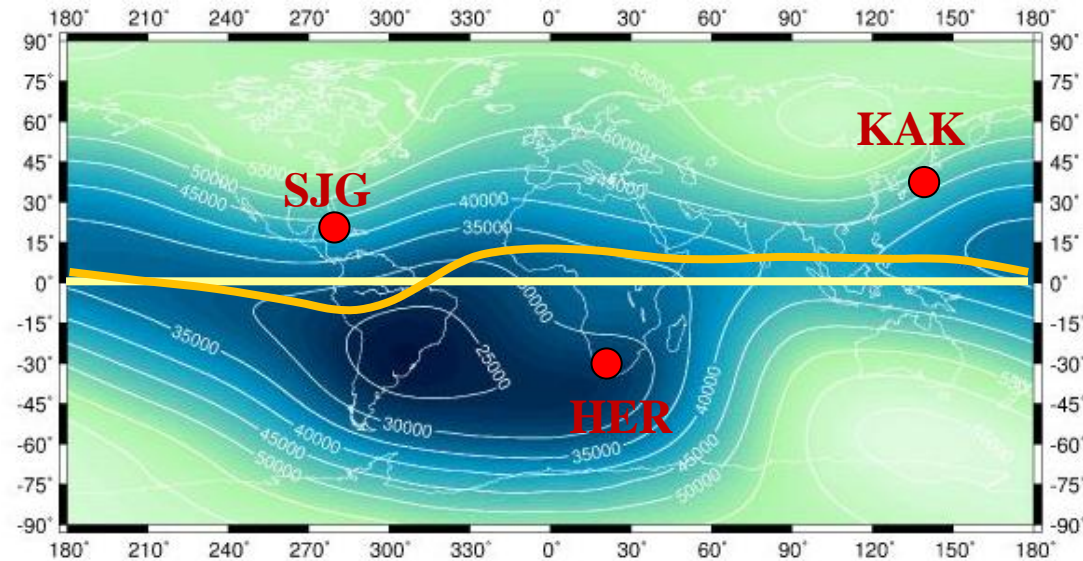
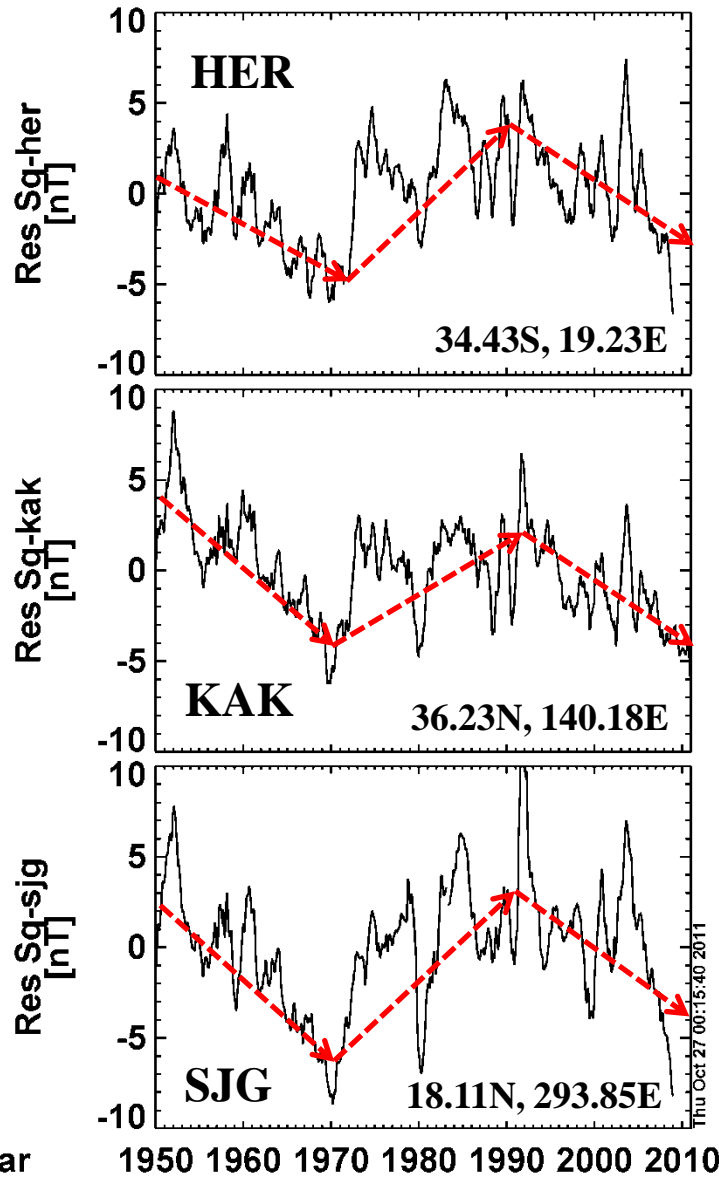


Res Sq at THL  
Power spectrum  
[(nT)<sup>2</sup> year]



## 3. Results

### 3.5 Long-term variation of residual Sq amplitude-2



Location of SJG, HER and KAK

○ Residual Sq amplitudes show **significant decrease and increase** at each observation point.

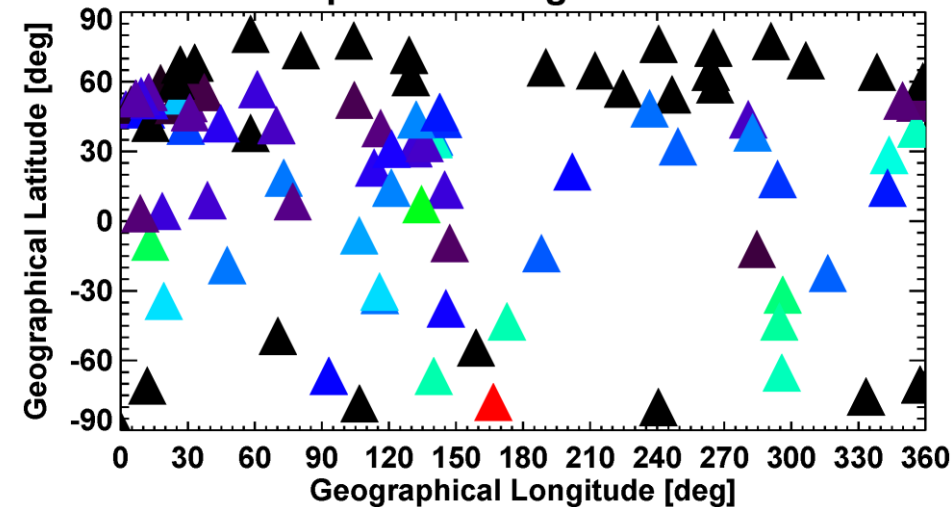
⇒ **Global phenomena?**

○ The res-Sq amplitudes become minimum around 1970 and 2010.

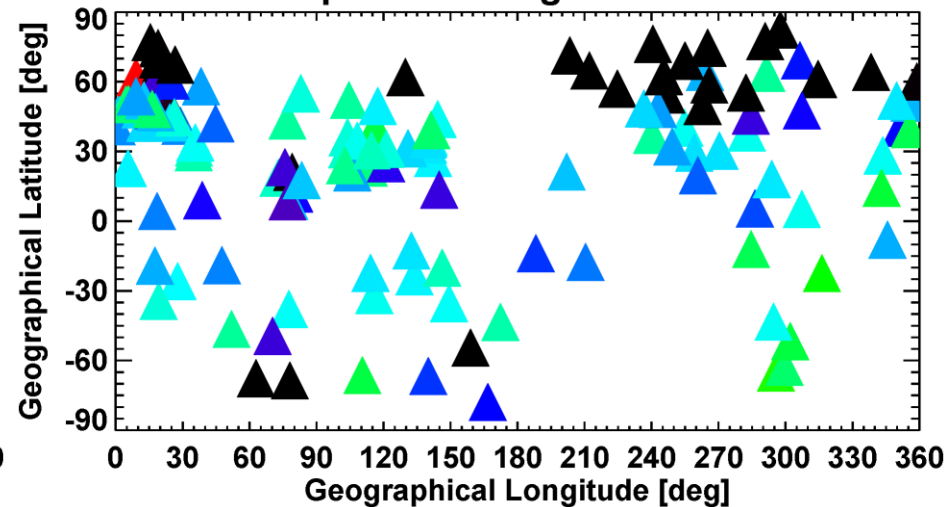
# 3. Results

## 3.6 Trends in the res-Sq amplitude (geographical distribution)

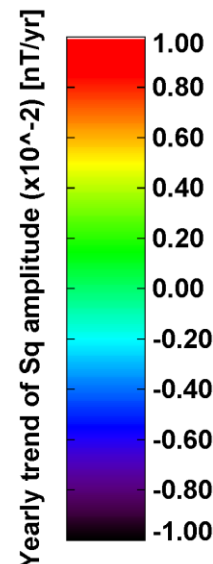
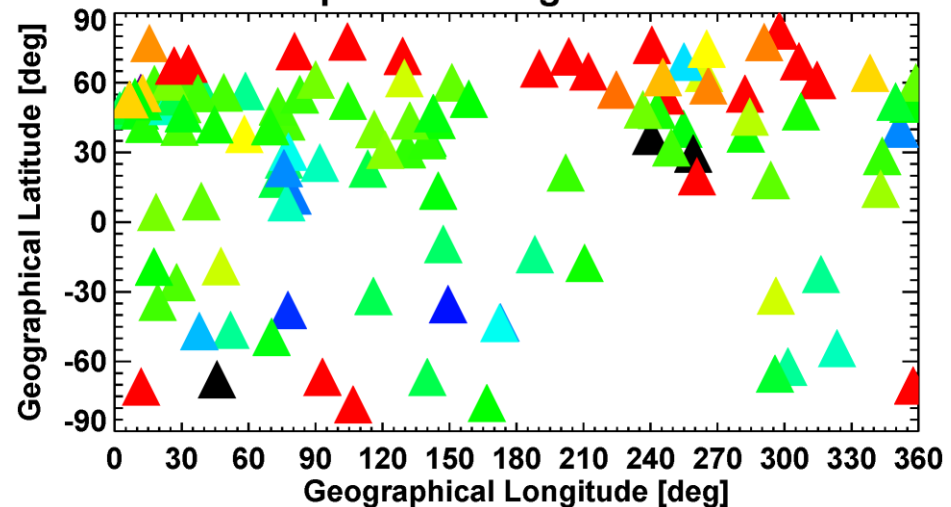
Sq trend during 1950-1969



Sq trend during 1990-2009



Sq trend during 1970-1989



Left and upper : 1950-1969

Left and bottom : 1970-1989

Right upper : 1990-2009

**Trends in the res-Sq amplitude show significant decrease and increase with its period of 20 yr.**





## 4. Discussion

### 4.1 Interpretation of long-term trends in the Res-Sq field

**Both long-term trends in the res-Sqp amplitude in the auroral and polar cap regions and in the Sq amplitude in the middle and low latitudes during 1950-2010 show significant decrease and increase with the 20-yr period.**

[Generation mechanism of Sqp and Sq fields]

①Sqp: **solar wind**→Polar ionospheric convection

②Sq: **solar irradiance**→thermospheric dynamo

$$\begin{aligned} J_{sqp} &= \Sigma \cdot E_{conv} \\ J_{sq} &= \Sigma \cdot (E_p + U \times B) \end{aligned}$$

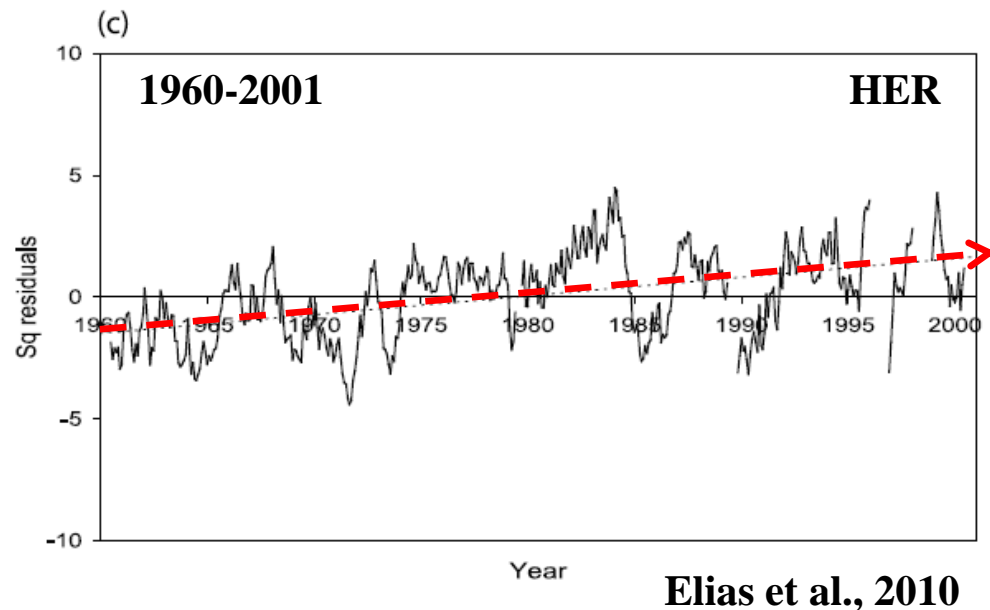
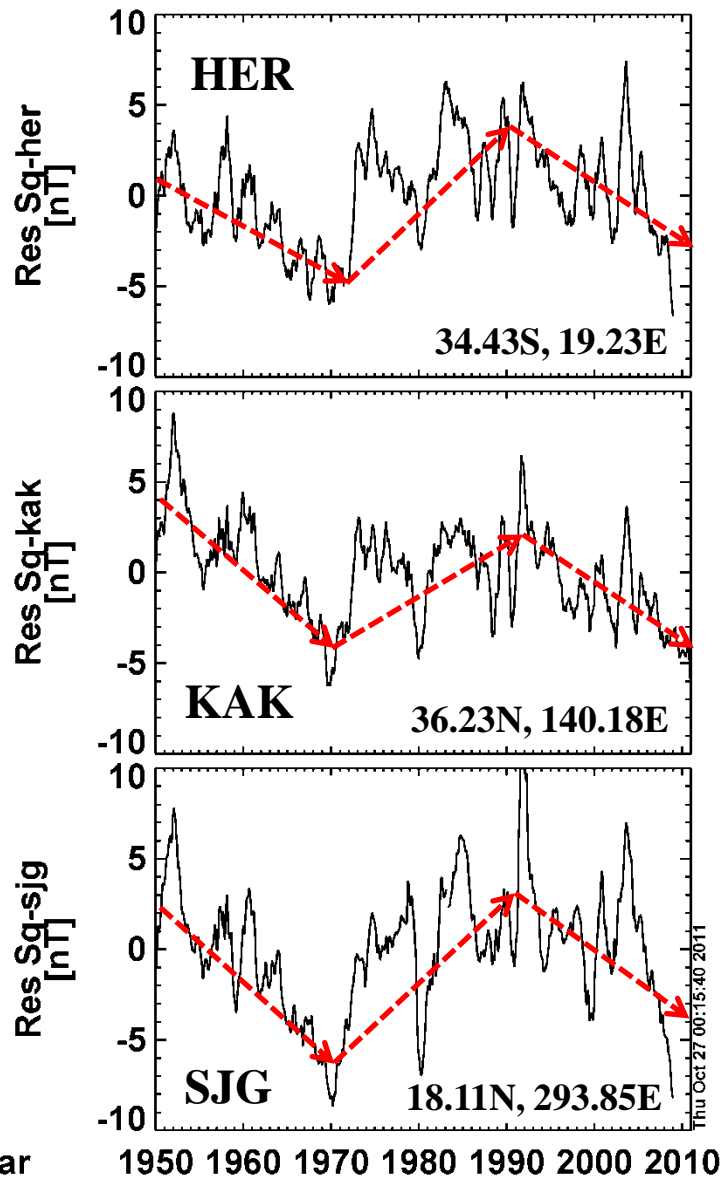
Although the generation mechanism of the Sqp field is different from that of the Sq one, **long-term trends in the residual Sqp and Sq fields show a similar tendency during 1951-2010**. Then, the variation of the ionospheric conductivity contributes significantly to the above trends.



**Inherent variation of the Earth's upper atmosphere ?**

## 4. Discussion

### 4.2 Comparison of the analysis result of the previous works

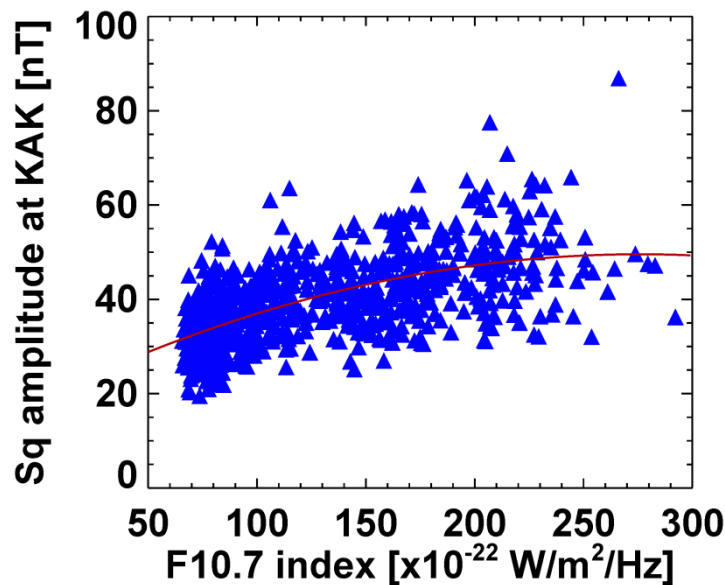


- Trends in the Sq field show decrease and increase phases with its 20-yr period.
- This is not consistent with that reported by Elias et al. [2010], who showed the linear trends in the Sq field.

## 4. Discussion

### 4.3 Implication of the Sq and F10.7 relationship

#### Relation between the F10.7 index and Sq amplitude



Ionospheric electron content (ICE) shows a linear relation up to 200 (F10.7).

**More than 200:  
Saturation**

**Second-order relationship**

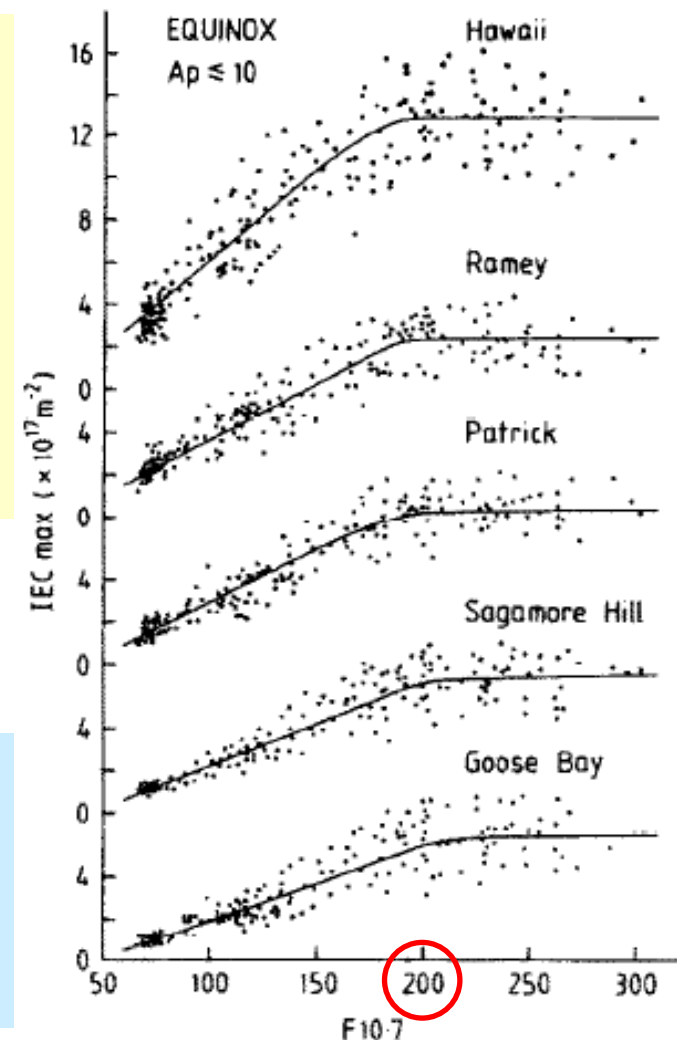
High F10.7 values do not exactly reflect on the EUV variation involving the formation of the ionosphere??

**(F10.7  $\Leftrightarrow$  EUV Nonlinear relationship)**

1981-1985

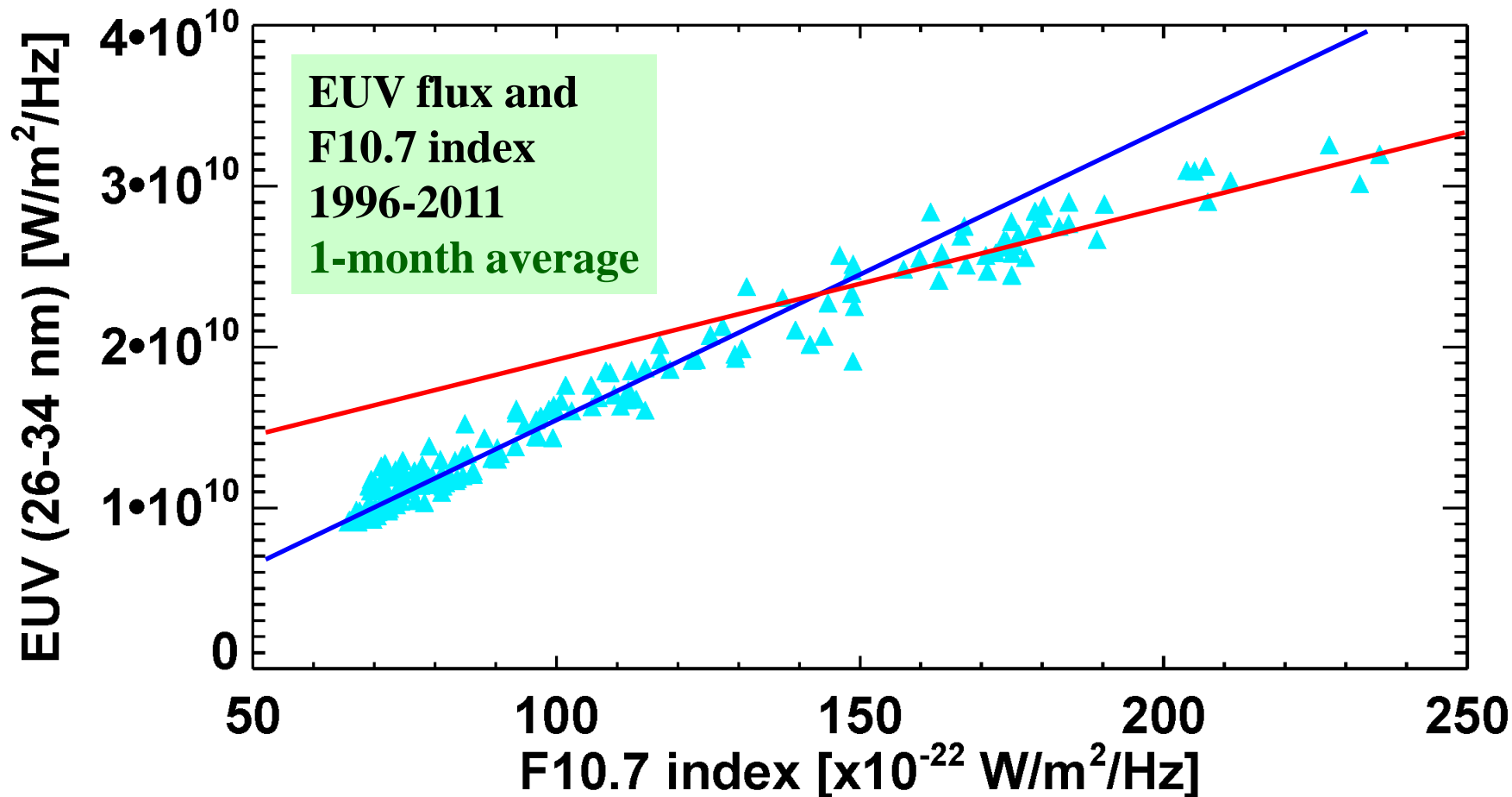
Balan et al., 1993

(Mar., Apr., Sep., Oct.)



## 4. Discussion

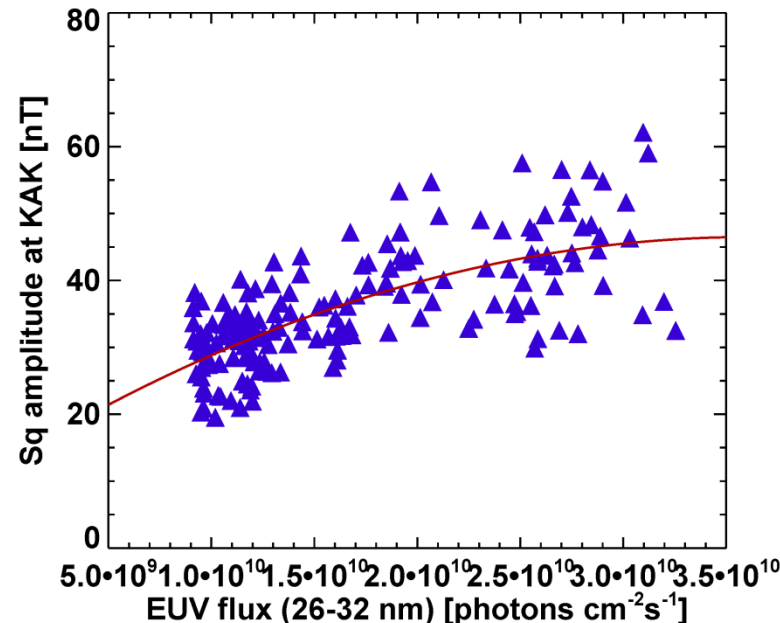
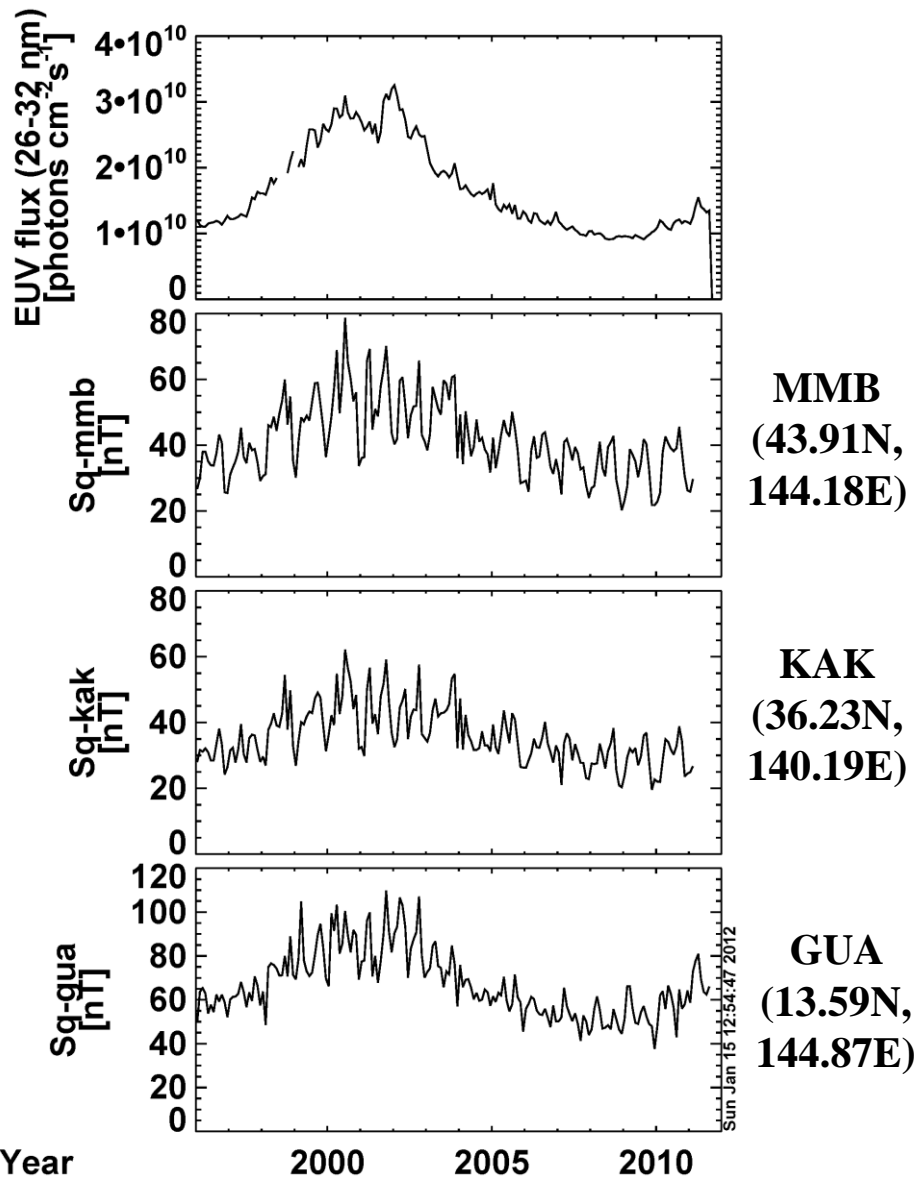
### 4.4 Relationship between the F10.7 index and EUV flux



Relationship between the F10.7 index and EUV flux is **not linear**, and **increasing rate of the EUV flux tends to decrease** for high F10.7 value of more than 150-180.

## 4. Discussion

### 4.5 Relationship between the EUV flux and Sq amplitude



The Sq amplitude does not show a linear relationship with the EUV solar flux linked to the formation of the Earth's ionosphere.

**(Sq ↔ EUV Nonlinear relationship)**

The Sq amplitude includes other parameters not linked to the EUV flux.



## 5. Conclusion

○ We investigated solar activity dependence and trends of the Sq fields using the long-term observation data of solar F10.7 index and geomagnetic field during 1950-2010. The analysis results and conclusion are summarized below.

1. The amplitude of the Sq field varies **with strong dependence on 11-yr solar activity**, and tends to increase with increase of the solar F10.7 index.
2. The long-term trends in the residual Sq amplitude calculating the second-order fitting curves between 1-month average F10.7 index and Sq amplitude **do not always show a positive value** during this period. They show **negative and positive variations with the period of 20 years**.
3. The trends in the residual Sqp amplitude driven by polar ionospheric convection generated by interaction between solar wind and magnetosphere also show the same tendency of the Sq amplitude in low and middle latitudes. **The global trends of the Sq and Sqp amplitudes reflect on inherent variation of the Earth's upper atmosphere.**
4. **Relationship between the F10.7, EUV solar fluxes and Sq amplitude is nonlinear**, which shows that increase rate of the Sq amplitude tends to decrease with increase of the F10.7 index.



## 6. Future works

### **1. A quantitative evaluation of the long-term trends in the Sq field using the ionospheric conductivity model.**

**From correlation analysis between the Sq amplitude and ionospheric conductivity, we quantitatively evaluate the contribution of inherent variations in the upper atmosphere. In this analysis, we exclude the effects of season and secular variation of the ambient magnetic field.**

### **2. Correlation analysis between the Sq amplitude and neutral wind in the lower thermosphere and mesosphere.**

**We clarify the relationship between the long-term variations of the Sq amplitude and neutral wind in the MLT region. In this analysis, we calculate the residual neutral wind from the second-order fitting curve between the F10.7 index and neutral wind. Here, we will use wind data obtained from the MF and meteor wind radars over Indonesia and Shigaraki MU radar.**